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FOREWORD

This paper was prepared for consideration for publication in the Journal of the American Concrete Institute. The manuscript was approved for publication by the Office, Chief of Engineers in December 1966. As indicated in the footnote on page 1 of the paper, it is based on U. S. Army Engineer Waterways Experiment Station (WES) Technical Memorandum 6-412, Report 2, which describes work done as a part of Item ES 026 of the Engineering Studies Program of the Office, Chief of Engineers.

Directors of the Waterways Experiment Station during the conduct of the work discussed and the preparation and publication of this report were Col. R. D. King, CE, Col. H. J. Skidmore, CE, Col. C. H. Dunn, CE, Col. A. P. Rollins, Jr., CE, Col. E. H. Lang, CE, Col. A. G. Sutton, Jr., CE, and Col. John R. Oswalt, Jr., CE. Mr. J. B. Tiffany was Technical Director.

An ACI Summary Paper
Based on a U. S. Army Engineer Waterways
Experiment Station Technical Report

FIELD EXPOSURE TESTS OF REINFORCED CONCRETE BEAMS*

by E. C. Roshore**

Synopsis

Two series of reinforced concrete beams were made and exposed to severe natural weathering at Treat Island, Maine.

Variables under study were thickness of concrete cover over and tensile stress in the reinforcing steel, position of the steel, and type of concrete and steel used.

Results after 15 winters of exposure of the first series of beams (Series A) indicated that the air-entrained beams were significantly more resistant to the weathering that the nonair-entrained beams, and that the beams with reinforcing steel having deformations conforming to ASTM Standard A 305 were more resistant to the weathering than those with reinforcing steel having old-style deformations. These tests formed the

*Prepared for submittal to the American Concrete Institute for consideration for publication. This is a summary, including some later results, of a report by E. C. Roshore entitled Tensile Crack Exposure Tests, Results of Tests of Reinforced Concrete Beams, 1955-1963, Technical Memorandum No. 6-412, Report 2, issued by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., in November 1964, copies of which may be obtained from Director, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 39180, for a payment of $0.50. If copies of this report become unavailable from the WES, reproduced copies can be obtained from ACI Headquarters at cost of reproduction.

** Research Materials Engineer, Thermal Research and Durability Section, Engineering Sciences Branch, Concrete Division, U. S. Army Engineer Waterways Experiment Station, Jackson, Miss.

basis for a change in Corps of Engineers practice in 1958 by which allowable steel stresses were increased from 18,000 to 20,000 psi (1260 to 1400 kg per sq cm). This change has resulted in a saving of cost in Corps of Engineers construction averaging $1.25 million per year since the change was made.

Results after 12 winters of exposure of the second series of beams (Series B) indicated that more exposure is needed to produce deterioration sufficient to permit unambiguous conclusions.

Exposure of both series of beams is continuing.

Introduction

Kennedy[1,2] described the first series of specimens made and tested in this program, summarized and discussed the results to 1954, and mentioned that an additional series of specimens had been made. Results of both series of specimens through 1964 have been published,[3] and results after 1964 are reported annually.[4]

The findings as reported in 1964[3] are summarized here and the data are brought up to date as of 1966. Siess[5] reported that, as a result of the early observations in these tests, the Corps of Engineers in 1958 increased allowable steel stresses from 18,000 to 20,000 psi (1260 to 1400 kg per sq cm) with a consequent saving in cost on its projects alone amounting to $7.50 million over the six-year period following the making of the change.

The study was begun in 1950 to develop information on the relation between various degrees of steel stress in reinforced concrete beams made

with both air-entrained and nonair-entrained concrete and deterioration caused by severe natural weathering.

In 1951, 82 beams (Series A) were made at the Waterways Experiment Station and installed at Treat Island, Maine, where they are exposed to the effects of severe natural weathering. Other variables were type of reinforcing steel, type of deformations of the reinforcing steel, thickness of concrete cover over steel, and position of steel in the beam at time of casting. After only three years, it was apparent that only air-entrained concrete beams were able to withstand the exposure.

In 1954, 76 additional beams (Series B), all of which were air-entrained, were made and exposed at Treat Island. Comparison of the effects of steel stress, type of deformations of reinforcing, and position of steel at time of casting were to be made.

The exposure of the beams in Series A and B has been continuous since 1951 and 1954, respectively. The remaining Series A beams have now undergone 15 winters of exposure; all of the Series B beams have had 12 winters of exposure.

Severe Weathering Exposure Station[4]

The test specimens are installed at mean-tide elevation. A cycle of freezing and thawing consists of the reduction of the temperature at the center of a beam to below 28 F (−2.22 C) and its subsequent rise. The number of freezing-and-thawing cycles obtained annually since 1951 ranged between 71 and 167 and is as follows:

Winter	Number	Winter	Number	Winter	Number
1951-52	101	1956-57	144	1961-62	89
1952-53	85	1957-58	71	1962-63	106
1953-54	111	1958-59	150	1963-64	135
1954-55	145	1959-60	71	1964-65	163
1955-56	167	1960-61	141	1965-66	130

Materials

The concrete contained crushed limestone aggregate (3/4-in. or 1.90-cm) and type II portland cement. Concrete mixture data[5] are given in table 1.

In Series A rail-steel bars conforming to ASTM A 16-50T and billet-steel bars conforming to ASTM A 15-50T were used. The billet-steel bars had deformations conforming to ASTM A 305-50T. Some of the rail-steel bars used had deformations conforming to ASTM A 305-50T and the others had deformations which did not conform to these requirements.

In Series B all of the reinforcing used was rail steel. Half of these bars had deformations conforming to ASTM A 305-50T while the other half had old-style deformations.

Test Beams

The test specimens were 7 ft 9 in. long (2.36 meters) and either 8, 9, or 10 in. wide (20.32, 22.86, or 25.40 cm). Beam depths varied from 12-3/16 in. (30.96 cm) to 14-1/4 in. (36.20 cm). The reinforcing bars were 7 ft 5 in. long (2.26 meters), and either No. 4, No. 5, No. 6, or No. 7 (or equivalent); two bars were positioned in each beam either near the top or at the bottom of the beam at the time of molding. In Series A

the bars were placed so that the nominal concrete cover over the steel was either 3/4 in. (1.90 cm) or 2 in. (5.08 cm); a nominal concrete cover of 2 in. (5.08 cm) was provided in Series B.

The beams were moist cured to an age of 28 days prior to ~~stressing~~ loading and shipping to the exposure station. Beams of similar size and of similar concrete insofar as possible were paired and loaded by third-point flexural loading* using spring and yoke devices with spacer gages. Nominal loads used (stress in reinforcing steel) were 20,000, 30,000, 40,000, and 50,000 psi (1400, 2100, 2800, and 3500 kg per sq cm).

In Series A, 72 beams were loaded; 10 were not loaded. In Series B, 64 beams were loaded and 12 beams were not.

Cracks developed in all of the loaded beams during the flexural loading ~~stressing~~. The cracks were all fine and irregular. The width of these cracks was not measured prior to exposure. Since 1956, the width of the cracks in both series of beams has been measured annually (except Series A in 1959).

Field Exposure

The test beams were installed on concrete sills on the beach at ages ranging from 90 to 120 days. When Series A was initially installed one beam of a pair was directly over the other. In the fall of 1956, the beams were turned on their sides to eliminate unequal exposure conditions resulting from the upright position.[1,2] The Series B beams were placed on their sides at installation.

The test specimens were inspected weekly for physical condition during each winter season and, prior to May 1959, weekly adjustments were made to

* this flexural loading is not a prestressing operation.

maintain correct deflections as indicated by the spacer gages. If correct gap openings could not be maintained, the pair of specimens was adjudged "failed" (unable to carry prescribed load), and the date of this "failure" was recorded. In May 1959, the hardware was replaced on all remaining specimens and the spacer gages were not replaced.

All specimens were also inspected annually (except 1965) by a panel of observers, from 3 to 16 persons, and evaluations of each beam were made. The beams were given a numerical rating ranging from 100 (negligible deterioration) to 0 (complete loss of load-carrying capacity). This rating was based on a system devised by Kennedy[1,2] from 1951 to 1959 and on a system devised by Bloor[3] since 1959. Ratio and proportion methods were used to obtain a continuous numerical rating with the same basis. The 1966 numerical ratings of the remaining beams ranged from 24 to 62 for Series A, and from 41 to 87 for Series B.

Test Results

The maximum width of cracks in both series of beams has been measured using a measuring magnifier with a least reading of 0.005 in. (0.127 mm). The 1966 maximum crack widths range to 0.030 in. (0.762 mm) for Series A and to 0.125 in. (3.175 mm) for Series B.

Comparisons were made based on the 1966 numerical ratings of dates of "failure" of single (unloaded) beams or pairs of loaded beams. Comparisons of each variable were only made between beams or pairs of beams in which the variable under consideration was the only difference between them (except for slight differences in diameter of reinforcing bars and beam size).

Series A

Only 17 of the original 82 beams now remain under test. As it is no longer possible to develop additional information about the effect of four of the variables, a "Test of Significance"[6] was conducted to aid in the interpretation of these particular comparisons. The probability of obtaining results such as were obtained for these four variables (type of concrete, thickness of concrete cover, type of steel, deformations of steel) was calculated for each of the comparisons. A probability of 0.10 was taken as the probability of significance; if the probability of occurrence is equal to or less than 0.10, the results are then considered to be significant.

Air-entrained concrete versus nonair-entrained concrete. In all seven of the comparable cases air-entrained concrete exhibited greater durability in the Treat Island environment (probability = 0.02, or highly significant).

Stress in reinforcing steel. Sixty-five comparisons were made. Based on these comparisons, the 1966 order of durability, from most durable to least durable, is 0 stress, 50,000-, 40,000-, 20,000-, and 30,000-psi stress.

3/4-in. versus 2-in. concrete cover. In 8 of the 14 comparable cases, the beams in which the reinforcing steel had a 3/4-in. cover exhibited greater durability than those with the 2-in. cover (probability > 0.50 or not significant).

Top-positioned steel versus bottom-positioned steel. In six of the ten comparable cases beams with the bottom-positioned steel have exhibited greater durability to date than beams with the top-positioned steel.

Rail steel versus billet steel. Under the rules selected for all of the comparisons there are no comparable cases on which to base valid comparisons of the two types of steel. However, if the 1954 numerical ratings are used, there are six comparable cases. In four of these six cases, beams with rail steel meeting A 305-50T exhibited greater durability than did beams with billet steel meeting the same specifications (Probability > 0.50 or not significant).

In 1959, samples of rail steel and billet steel used in this exposure were analyzed. The rail-steel sample contained 0.44% copper, while the billet-steel sample contained only 0.08% copper.

Rail-steel deformations: A 305 versus old-style deformations. In all five of the comparable cases, beams with rail steel meeting A 305 exhibited greater durability than did beams with rail steel with old-style deformations (probability = 0.06 or significant).

Series B

All Series B beams are still under test.

Stress in reinforcing steel. Thirty-six comparisons were made. Based on these comparisons, the 1966 order of durability from most durable to least durable is 20,000-, 30,000-, 40,000-, 50,000- and 0-psi stress.

Top-positioned steel versus bottom-positioned steel. In 33 of the 46 comparable cases, beams with the top-positioned steel have exhibited greater durability to date than beams with bottom-positioned steel.

Rail-steel deformations: A 305 versus old-style deformations. In 29 of the 47 comparable cases, beams with rail steel meeting A 305 have exhibited greater durability to date than beams with rail steel with old-style deformations.

Width of cracks - Series A and Series B

There appears to be a correlation in both series between maximum crack width and stress in reinforcing steel; i.e., maximum crack width increases with increasing stress (table 2). This does not appear to be true of changes in crack width from 1957 to 1966.

Conclusions

Series A (Installed in November 1951)

It was concluded that, in this exposure air-entrained beams are significantly more durable than the nonair-entrained beams and beams containing rail steel with deformations conforming to ASTM A 305 are significantly more durable than the concrete beams containing rail steel with the old-style deformations.

The exposure of the remaining 17 beams will be continued until a sufficient number of beams have failed to provide all the pertinent information which can be obtained from this particular experimental design. Continued exposure will develop more information on the effect of steel stress and position of steel at the time of casting on the durability of the concrete beams in this exposure.

Series B (Installed in November 1954)

Test data developed to date do not permit definite conclusions to be drawn on the effect of steel stress, type of deformations of reinforcing steel, and position of steel at the time of casting on the durability of the concrete beams in severe weather exposure. Since none of the beams have failed, this exposure will be continued until a sufficient number of beams

have failed to provide all of the pertinent information which can be obtained from this particular experimental design. Continued exposure will develop more information in regard to the effects of all of the test variables on the durability of the concrete beams in this exposure.

References

1. U. S. Army Engineer Waterways Experiment Station, CE, Tensile Crack Exposure Tests, by T. B. Kennedy. Technical Memorandum No. 6-412, Vicksburg, Miss., July 1955.

2. Kennedy, T. B., "Tensile crack exposure tests of stressed reinforced concrete beams." Proceedings, American Concrete Institute, vol 52 (1955-1956), pp 1049-1063.

3. U. S. Army Engineer Waterways Experiment Station, CE, Tensile Crack Exposure Tests, Results of Tests of Reinforced Concrete Beams, 1955-1963, by E. C. Roshore. Technical Memorandum No. 6-412, Report 2, Vicksburg, Miss., November 1964.

4. __________, Investigation of Performance of Concrete and Concreting Materials Exposed to Natural Weathering, by E. C. Roshore. Technical Report No. 6-553 with annual supplements, Vicksburg, Miss., June 1960.

5. __________, Handbook for Concrete and Cement, with quarterly supplements, Vicksburg, Miss., August 1949.

~~6. Sidor, [illegible]. L., Exposure Tests of Stressed Reinforced Concrete Beams. Unpublished report submitted to Reinforced Concrete Research Council of ASCE, February 1960.~~

6. Davies, O. L., Statistical Methods in Research and Production, 3d ed., rev. Hafner Publishing Company, New York, N. Y., 1958.

7. Siess, C. P., "Work of the Reinforced Concrete Research Council." Journal, American Concrete Institute, News-Letter, vol 63, No. 1 (Jan 66), pp NL 13-20.

Table 1

Concrete Mixture Data

	Series A Concrete		Series B Concrete
	Nonair-Entrained	Air-Entrained	Air-Entrained
Slump, in. (cm)	3 to 3-1/2 (7.62 to 8.89)	3 to 3-1/2 (7.62 to 8.89)	2-1/4 to 3-1/2 (5.72 to 8.89)
Air Content, %	-	4.5 ± 0.5	5.0 to 7.0
Cement factor, bags/cu yd (kg/cu m)	5.20 (287.77)	5.35 (296.07)	5.29 (292.75)
Water-cement ratio, by wt	0.70	0.60	0.58
Sand:total aggregate, %	48.5	42.	42.
Avg compressive strength, psi, (kg/sq cm):			
7 days	2650 (185.50)	2695 (188.65)	2325 (162.75)
28 days	3855 (269.85)	3820 (267.40)	3240 (226.80)
E x 10^{-6}, psi (kg/sq cm)	4.94 (0.35)	4.86 (0.34)	4.09 (0.29)

Table 2

Average Measured Crack Widths

Stress Level		No. of Beams Remaining in 1966	1957 Average Maximum Crack Width		1966 Average Maximum Crack Width		1957-1966 Change in Maximum Crack Width (+ = increase; − = decrease)	
psi	kg/sq cm		1/1000 in.	mm	1/1000 in.	mm	1/1000 in.	mm
			Series A					
0	0	1	0.00	0.00	0.00	0.00	0.00	0.00
20,000	1400	4	8.75	0.22	7.50	0.19	-1.25	-0.03
30,000	2100	4	8.75	0.22	8.75	0.22	0.00	0.00
40,000	2800	4	12.50	0.32	23.75	0.60	+11.25	+0.28
50,000	3500	4	16.25	0.41	25.00	0.64	+8.75	+0.23
			Series B					
0	0	12	1.67	0.04	2.50	0.06	+0.83	+0.02
20,000	1400	16	12.81	0.33	10.62	0.27	−2.19	-0.06
30,000	2100	16	15.31	0.39	24.06	0.61	+8.75	+0.22
40,000	2800	16	18.75	0.48	36.88	0.94	+18.13	+0.46
50,000	3500	16	31.88	0.81	46.56	1.18	+14.68	+0.37